Answers

Chapter 1

1.1 X-rays and nuclear radiation

A Ionizing radiation (p.1)

1 energy, vacuum, waves

2 ionize, electrons, ions, X-rays, nuclear

3 living cells

B X-rays (p.1)

1 fast-moving, metal

① Electrons, negative

② accelerated

③ positive, X-rays

2 low, bones

C Nuclear radiation (p.2)

1 radioactive, radioactivity

2 blacken

3 (a) helium nuclei, electrons

(b) +2, 0 / no charge

(c) *c*

1.2 Radioactivity

A Background radiation (p.3)

1 ionizing

2 (a) radon

(b) medical

B Safety precautions (p.3)

1 (a) lead

(d) minimize

(e) warning signs

C Ionizing power (p.3)

1 electrons, ions, ionized

2 ionizing power

3 spark counter, sparks, more

4 (b) a few sparks

(c) no sparks

α, β, γ

D Cloud chamber tracks (p.5)

1 diffusion cloud chamber

2 clearer / thicker

Experiment

① dry ice

3 α source: thick, straight

β source: thin, twisted

γ source: scattered, hardly

4 right-angled fork, helium nuclei

E Geiger-Müller tube (G-M tube) (p.7)

1 counter

2 Background, background count rate

F Range and penetrating power (p.8)

Experiment

③ *B*

④ range

1 γ, β, α

2 (a) paper

(b) aluminium

(c) lead

γ, β, α

3 short, energy

Checkpoint 1

(a) slightly fluctuated

(b) β radiation, about the same, α, is not, aluminium plate, β, is, lead block, γ, is not

G Deflections in an electric field and a magnetic field (p.10)

1 charge

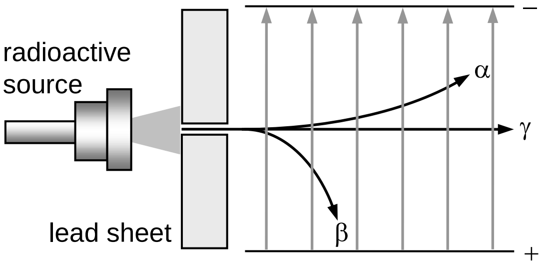
(a) (i) positively, same

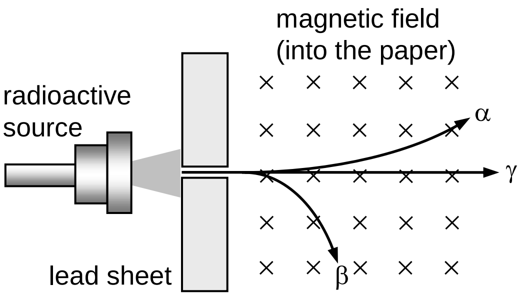
(ii) negatively, opposite

(b) Fleming's left-hand rule

2 mass, heavier, smaller

3





Experiment

② lead

④ slab-shaped magnets, highest / maximum

Checkpoint 2

(a) β radiation

(b) more, reduced, towards

H Comparison of α, β and γ radiation (p.12)

(a) helium, electrons, EM

(d) strong, very weak

(e) paper, 5-mm aluminium, 25-mm lead

(f) centimetres, metres

(i) straight, twisted

Chapter 2

2.1 The atomic model (p.13)

1 positive, mass, nucleus, empty space, Electrons

2 protons, neutrons, nucleons

3

Type of particle	Relative charge	Relative mass
proton	+1	1
neutron	0	1
electron	–1	$\frac{1}{1800}$

4 proton number, protons

5 mass number, protons, neutrons

6 neutron number

8 nuclide, radionuclide

9 Isotopes, Radioisotopes

Checkpoint 1

(a)

Nuclide	Notation	Number of protons	Number of neutrons
P	${}^{12}_{4}P$	4	8
Q	${}^{12}_{5}Q$	5	7
R	${}^{11}_{4}R$	4	7

(b) *P* and *R*

2.2 Radioactive decay

A Radioactive decay (p.15)

1 nuclear radiation, radioactive decay

2 parent nucleus, daughter nucleus, decay products

3 unchanged

4 transmutation

B Alpha decay (p.15)

1 α particle, helium

2 ${}^{4}_{2}\text{He}$

3 is

C Beta decay (p.16)

1 electron, β particle

2 ${}^{0}_{-1}\text{e}$

3 is

D Gamma emission (p.16)

1 gamma rays

3 is not

Checkpoint 2

(a) ${}^{232}_{90}\text{Th} \longrightarrow {}^{228}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

(b) ${}^{228}_{89}\text{Ac} \longrightarrow {}^{228}_{90}\text{Th} + {}^{0}_{-1}\text{e}$

E Decay series (p.17)

2 α decay, ↓ by 2, ↑ by 1

Checkpoint 3

(a) Mass number of *X*

$= 214 - 2 \times 4 = 206$

Atomic number of *X*

$= 84 - 2 \times 2 - 2 \times (-1) = 82$

Number of neutrons in *X*

= mass number – atomic number

$= 206 - 82 = 124$

(b) Number of α particles emitted

$= \frac{\text{change in mass number}}{\text{mass number of } \alpha \text{ particle}}$

$= \frac{237 - 205}{4}$

$= 8$

Let the number of β particles emitted in the complete series be *y*.

The decay equation can be written as:

$${}^{237}_{93}\text{Np} \longrightarrow {}^{205}_{81}\text{Tl} + 8\,{}^{4}_{2}\text{He} + y\,{}^{0}_{-1}\text{e}$$

Consider the atomic numbers.

$$93 = 81 + 8 \times 2 + y \times (-1)$$

$$y = 4$$

The nuclide emits 4 β particles.

F Characteristics of radioactive decay (p.19)

1 radioactive nuclei, 'decayed', decay curve

2 random

3 activity, becquerels

4 directly proportional, kN, decay constant, probability, fraction

5 constant, half-life, nuclei, activity

6 $A_0 \times \left(\frac{1}{2}\right)^n$

7 half-life

8 background radiation, corrected count rate

Checkpoint 4

(a) Count rate due to background radiation

= 20 counts per min

(b) Initial count rate due to the sample

= 140 – 20 = 120 counts per min

Expected count rate measured after 1 half-life

= half of the initial count rate due to the sample + count rate due to background radiation

$= \frac{120}{2} + 20$

= 80 counts per min

From the graph, the half-life of the sample is 7 minutes.

Checkpoint 5

D

9 $A_0 e^{-kt}$

10 $\frac{\ln 2}{k}$

Checkpoint 6

(a) Apply $N = N_0e^{-kt}$. When $t = t_{\frac{1}{2}}$, $N = \frac{N_0}{2}$.

$$\frac{N_0}{2} = N_0 e^{-kt_{\frac{1}{2}}}$$

$$e^{kt_{\frac{1}{2}}} = 2$$

$$kt_{\frac{1}{2}} = \ln 2$$

$$t_{\frac{1}{2}} = \frac{\ln 2}{k}$$

(b) By $t_{\frac{1}{2}} = \frac{\ln 2}{k}$,

$$k = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{\ln 2}{56} = 0.012\ 38\ \text{s}^{-1}$$

Activity A after 5 minutes

$= A_0e^{-kt}$

$= 1000 \times e^{-0.012\ 38 \times (5 \times 60)}$

= 24.4 Bq

2.3 Uses of radioisotopes and radiation safety

A Use of radioisotopes (p.24)

1 Penetrating, half-life

2 activity, fixed, decreases, 5730 years

Checkpoint 7

By $t_{\frac{1}{2}} = \frac{\ln 2}{k}$,

$$k = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{\ln 2}{5730 \times 3.16 \times 10^7} = 3.83 \times 10^{-12}\ \text{s}^{-1}$$

By $A = A_0e^{-kt}$,

$$t = -\frac{1}{k}\ln\left(\frac{A}{A_0}\right)$$

$$= -\frac{1}{3.83 \times 10^{-12}}\ln\left(\frac{0.1}{0.5}\right)$$

$= 4.20 \times 10^{11}$ s

$= \frac{4.20 \times 10^{11}}{3.16 \times 10^7}$ years

= 13 300 years

∴ The age of the ancient wood sample is 13 300 years.

3 γ, short

Checkpoint 8

penetrate the skin and soft tissues, reduce to a low

level

4 γ, cancer cells

B Radiation safety (p.27)

1 α, ionizing

2 γ, penetrating

3 equivalent dose, α, sieverts

4 3 mSv, 1 mSv

5 (a) radiation

(b) radioactive sources

(c) lead

Chapter 3

3.1 Nuclear fission and fusion

A Nuclear fission (p.28)

1 Nuclear fission

(b) energy

(c) neutrons

2 neutron, slow-moving

3 neutrons, chain reaction

4 escape, large, one, critical mass

Checkpoint 1

neutrons, does not release any neutron, cannot

B Nuclear fusion (p.29)

1 Nuclear fusion

2 low, larger

3 high temperature, kinetic energy

4 fusion

3.2 Mass-energy relationship

A Units of mass and energy in atomic scale (p.30)

1 atomic mass unit, carbon-12 atom, 1.661×10^{-27}

3 electron-volt, 1.60×10^{-19}, 1.60×10^{-19}

B Mass-energy equivalence (p.30)

1 mass, energy

2 mass-energy relationship, Δmc^2, J, kg

Checkpoint 2

Apply $\Delta E = \Delta mc^2$.

(a) $\Delta E = \Delta mc^2 = 0.001 \times (3.00 \times 10^8)^2$

$= 9.00 \times 10^{13}$ J

$\therefore$ The energy released is 9.00×10^{13} J.

(b) $\Delta m = \dfrac{\Delta E}{c^2} = \dfrac{100\,000}{(3.00 \times 10^8)^2} = 1.11 \times 10^{-12}$ kg

$\therefore$ The mass is 1.11×10^{-12} kg.

3 energy, 931

Checkpoint 3

(a) Energy $= \dfrac{2.05 \times 10^{-28}}{1.661 \times 10^{-27}}$

$= 0.123\,420$ u

(b) Energy $= 2.05 \times 10^{-28} \times (3.00 \times 10^8)^2$

$= 1.85 \times 10^{-11}$ J

(c) Method 1 ($\to$ u $\to$ MeV):

Energy $= \dfrac{2.05 \times 10^{-28}}{1.661 \times 10^{-27}} \times 931$

$= 115$ MeV

Method 2 ($\to$ J $\to$ MeV):

Energy $= \dfrac{2.05 \times 10^{-28} \times (3.00 \times 10^8)^2}{1.60 \times 10^{-19} \times 10^6}$

$= 115$ MeV

Checkpoint 4

(a) Consider the mass numbers.

$235 + 1 = 141 + 92 + k \times 1$

$k = 3$

(b) Total mass before reaction

$= 235.043\,923 + 1.008\,665$

$= 236.052\,588$ u

Total mass after reaction

$= 140.914\,403 + 91.926\,173 + 3 \times 1.008\,665$

$= 235.866\,571$ u

Loss in mass Δm

$= 236.052\,588 - 235.866\,571$

$= 0.186\,017$ u

Energy released ΔE

$= \Delta mc^2$

$= (0.186\,017 \times 1.661 \times 10^{-27}) \times (3.00 \times 10^8)^2$

$= 2.78 \times 10^{-11}$ J

Checkpoint 5

(a) Bismuth-210 undergoes a β decay as follows:

$$^{210}_{83}\text{Bi} \longrightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\beta$$

E = loss in mass

= 209.984 121 – (209.982 874 + 0.000 549)

= 0.000 698 u

= $(0.000\ 698 \times 1.661 \times 10^{-27}) \times (3.00 \times 10^{8})^2$

= 1.043×10^{-13} J

≈ 1.04×10^{-13} J

(b) Number of bismuth-210 nuclei (N)

$$= \frac{\text{total mass}}{\text{mass of each nucleus}}$$

$$= \frac{0.001}{209.984121 \times 1.661 \times 10^{-27}}$$

= 2.867×10^{21}

Decay constant k

$$= \frac{\ln 2}{t_{\frac{1}{2}}}$$

$$= \frac{\ln 2}{5.01 \times 24 \times 3600}$$

= 1.601×10^{-6} s^{-1}

Power due to the β decays

= number of β decay occurring in each second × E

= $(kN) \times E$

= $(1.601 \times 10^{-6} \times 2.867 \times 10^{21}) \times 1.043 \times 10^{-13}$

= 479 J

3.3 Applications of nuclear energy

A Nuclear power (p.34)

1 shortage, fossil fuels

2 fission

3 nuclear reactor

5 nuclear waste

6 (a) (ii) transport

(iv) air pollutants

(b) (i) renewable

(ii) nuclear weapons

(iii) thermal pollution

7 (a) (i) seawater

(ii) non-radioactive

(b) (i) high temperature

Checkpoint 6

(a) Energy released

= loss in mass

= (2.013 553 + 3.015 500) – (4.001 506 + 1.008 665)

= 0.018 882 u

= 0.018 882 × 931

= 17.6 MeV

(b) Minimum mass of $^{2}_{1}\text{H}$

$$= \frac{\text{total energy released}}{\text{energy released in one reaction}} \times \text{mass of } {}^{2}_{1}\text{H in each reaction}$$

$$= \frac{1 \times 10^{23}}{17.6} \times (2.013\ 553 \times 1.661 \times 10^{-27})$$

= 1.90×10^{-5} kg

(c) A very high temperature is required for the fusion to occur, but no actual solid container can withstand this.

B Nuclear weapons (p.36)

1 atomic, hydrogen, neutron, uncontrolled

3 neutrons, buildings